DiPOLE - An Efficient and Scalable HEC-DPSSL System

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Science & Technology Facilities Council
Central Laser Facility

Motivation

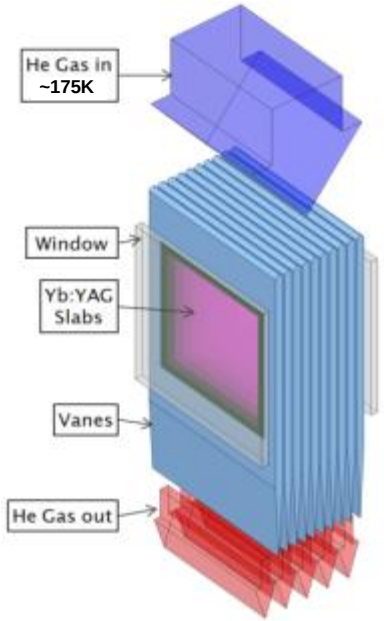
- Develop next generation high-energy PW-class lasers
  - Multi-J to kJ, multi-Hz, multi-% efficiency
- Enhance laser plasma research capabilities
  - Ultra-intense light-matter interactions
- Develop real world applications
  - Ultra-intense light-matter interactions
  - Compact laser driven particle accelerators
  - Laser driven UV & X-ray sources
  - Inertial confinement fusion
- HEC-DPSSL amplifiers needed
  - Pumping fs-OPCPA or Ti:S amplifiers
  - ns-drive laser for ICF

Beamline Facility

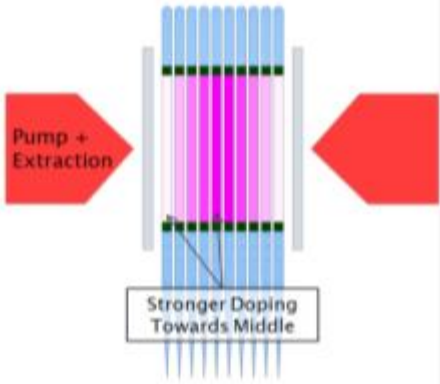
CALTA
Centre for Advanced Laser Technology & Applications

DiPOLE Amplifier Concept

- Diode-pumped multi-slab amplifier
  - Ceramic Yb:YAG gain medium
  - Co-sintered absorber cladding for ASE suppression
- Distributed face-cooling by stream of cold He gas
  - Heat flow along beam direction
  - Low overall aspect ratio & high surface area
- Operation at cryogenic temperatures
  - Higher o-o efficiency – reduction of re-absorption
  - Increased gain cross-section
  - Better thermo-optical & thermo-mechanical properties
- Graded doping profile
  - Equalised heat load in each slab
  - Reduces overall thickness (up to factor of ~2)
- Scalable design
  - 10 J, 100 J & 1 kJ

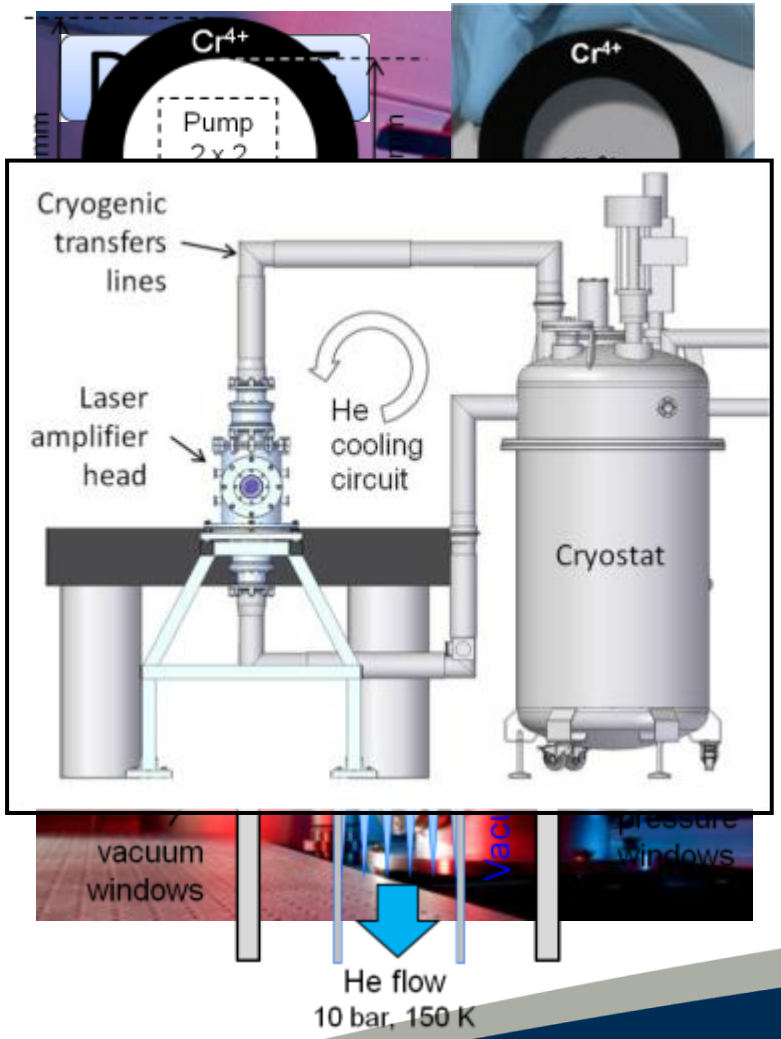


Schematic of 1 kJ head design



DiPOLE Prototype Amplifier

- Aims
  - Demonstrate viability of concept
  - Validate & calibrate numerical models
  - Test cryogenic gas-cooling technology
  - Test (other) ceramic gain media
- Specification
  - 10 J @ 10 Hz, 25% o-o efficiency
- Design
  - 4 x co-sintered ceramic YAG disks
    - 1.1 & 2.0 at% Yb^{3+} doping
    - Cr^{4+} absorbing cladding
  - Aerodynamically shaped vanes
    - CFD modelling $\Delta T \sim 3$ K
  - Design temperature ~ 175 K
  - LN_2 based cryogenic gas cooling system

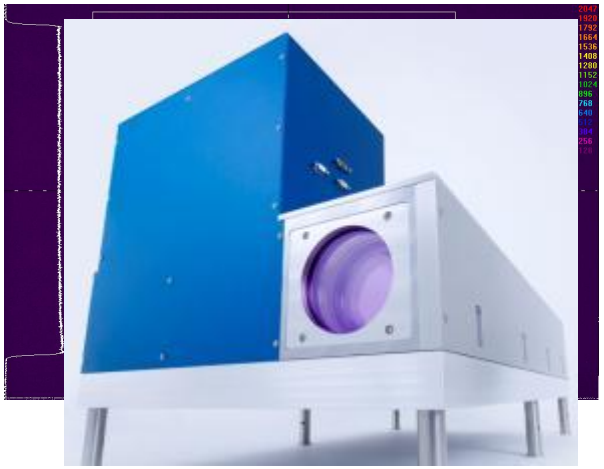


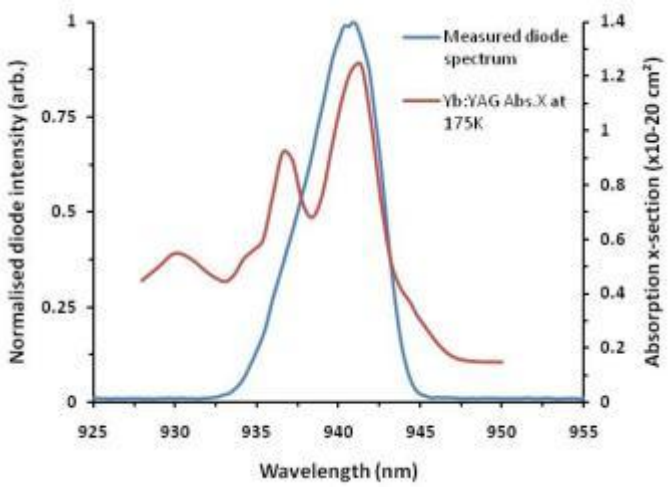
Diode Pump Laser

- Built by Consortium
  - Ingeneric, Amtron & Jenoptic

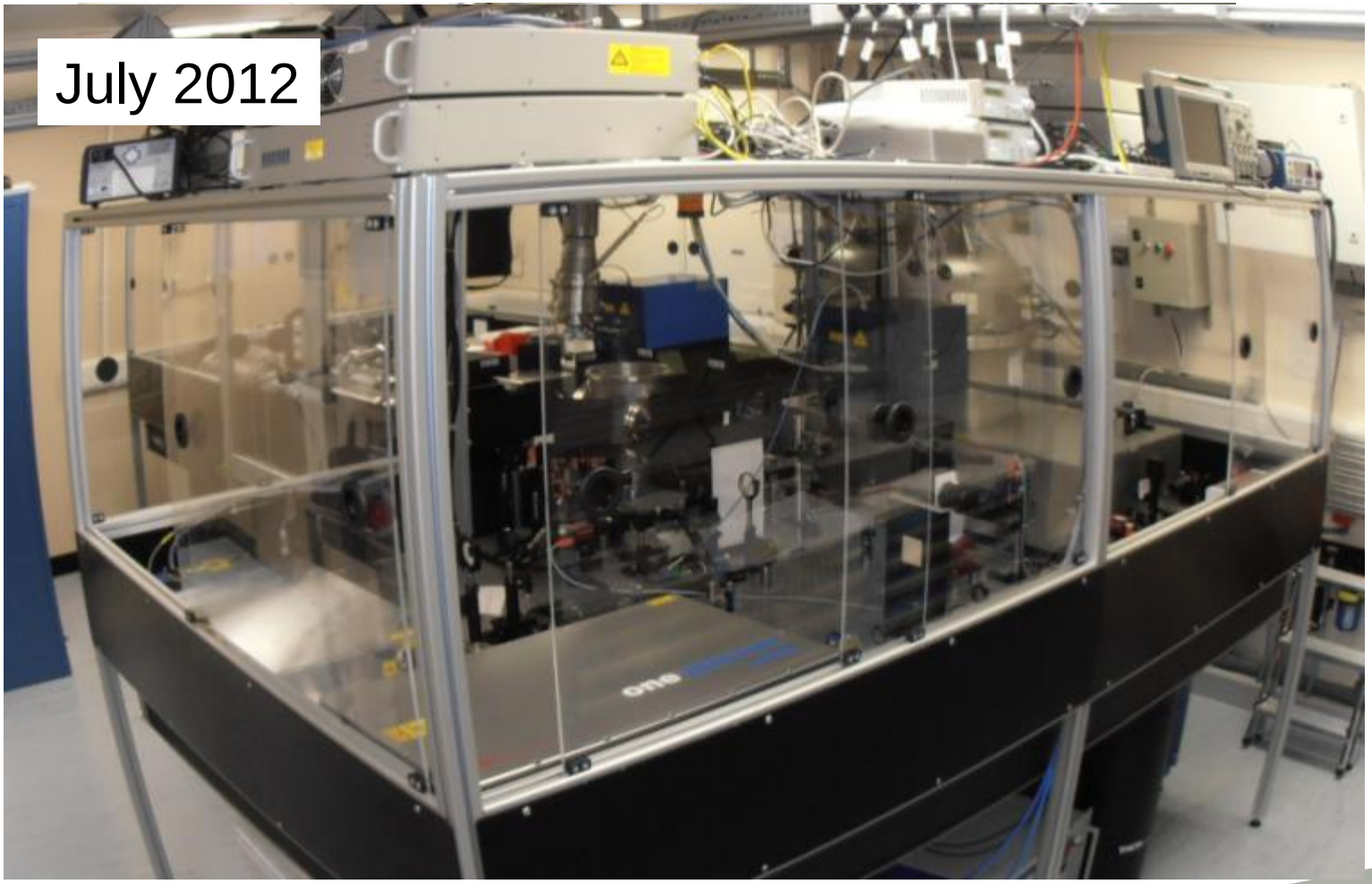
ingeneric AMTRON JENOPTIK

- Two systems supplied
  - $\lambda_0 = 939$ nm, $\Delta\lambda_{FWHM} < 6$ nm
    - 80% energy within $\pm$ 3 nm
    - 33% energy within $\pm$ 1 nm
  - Peak power 20 kW, single-shot to 10 Hz
  - Pulse duration 0.2 to 1.2 ms
  - Square beam 20 mm x 20 mm
  - Divergence 6° x 4° (H x V)
  - Brightness ~ 0.7 kW/cm²/sr



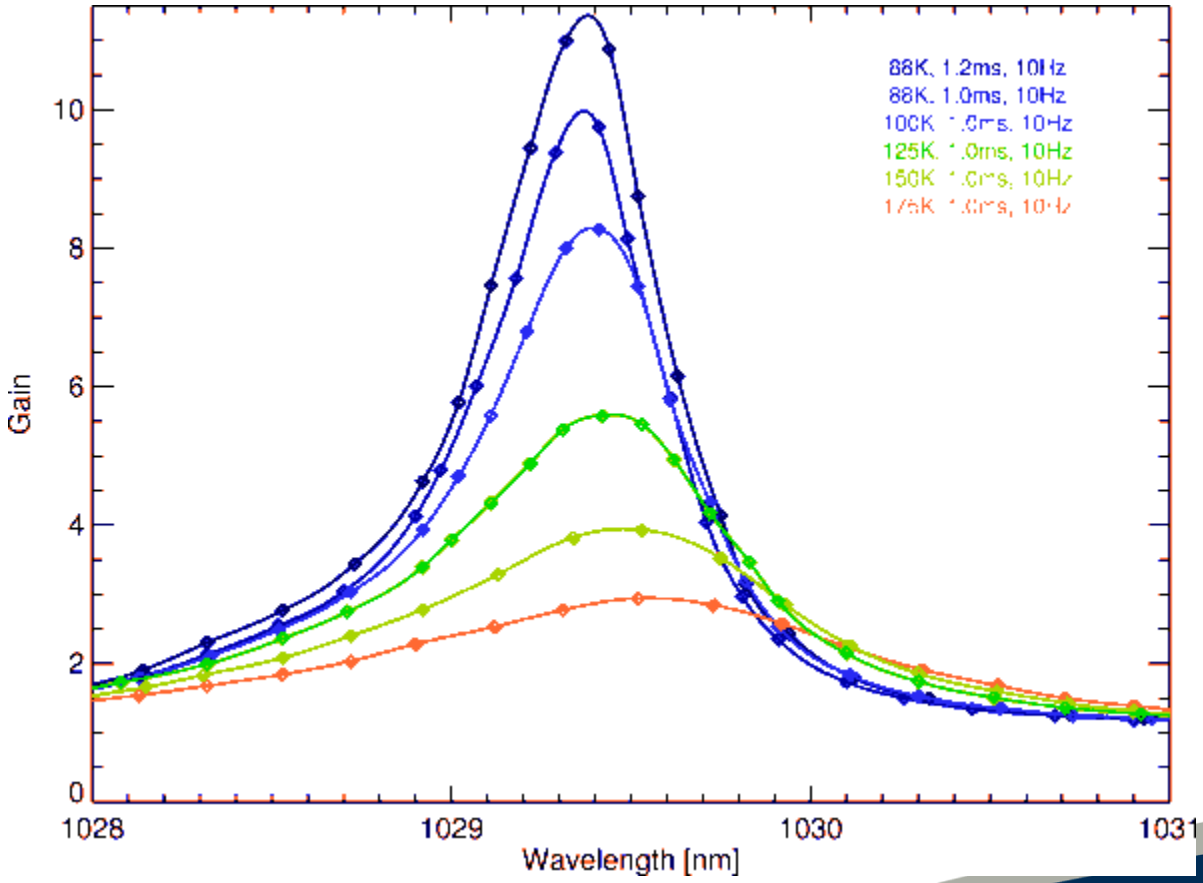


DiPOLE Laboratory



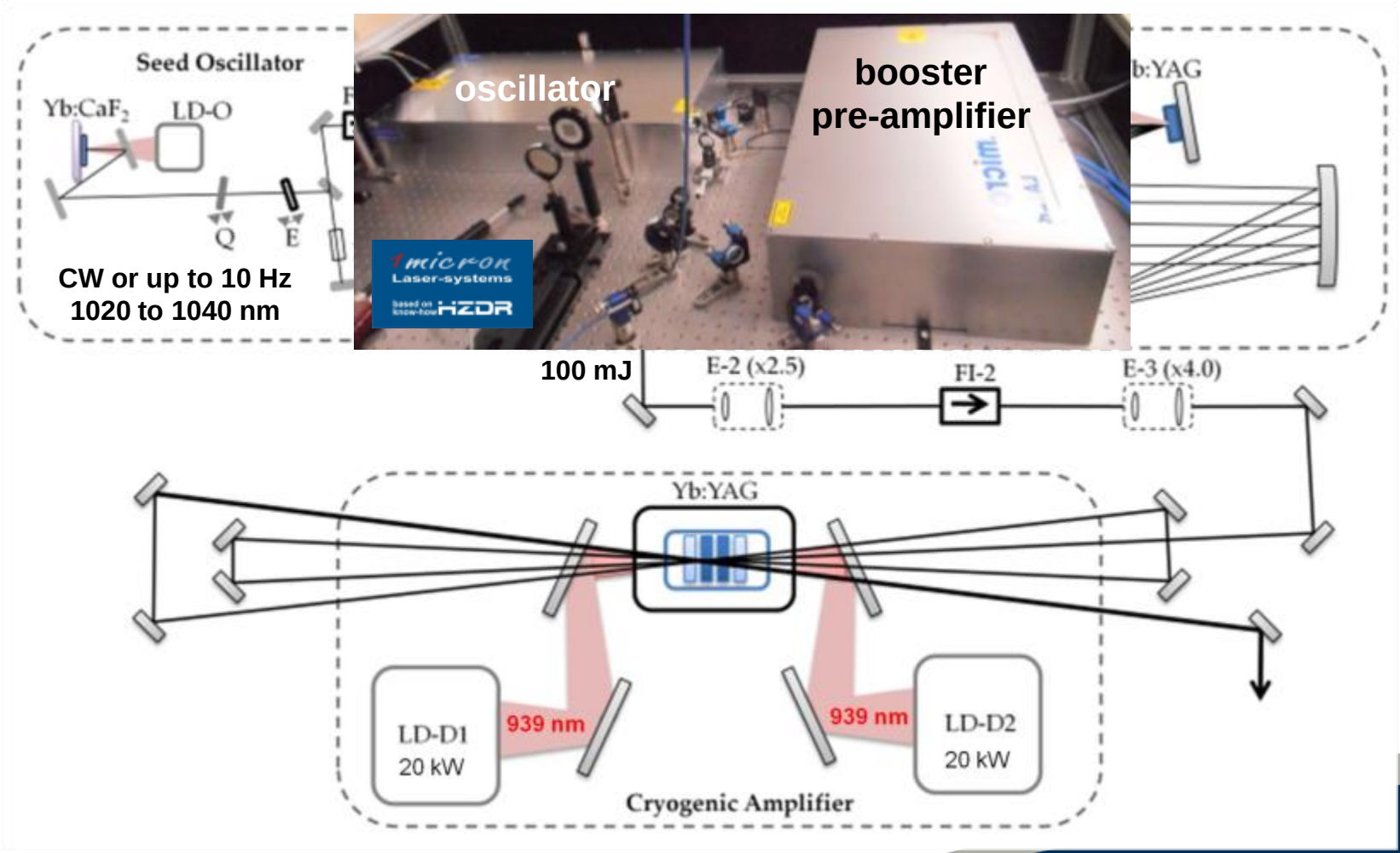
Initial Amplification Results – Winter 2011

- Gain v. Temperature & Wavelength
  - Single-pass measurement using CW tuneable ECDL

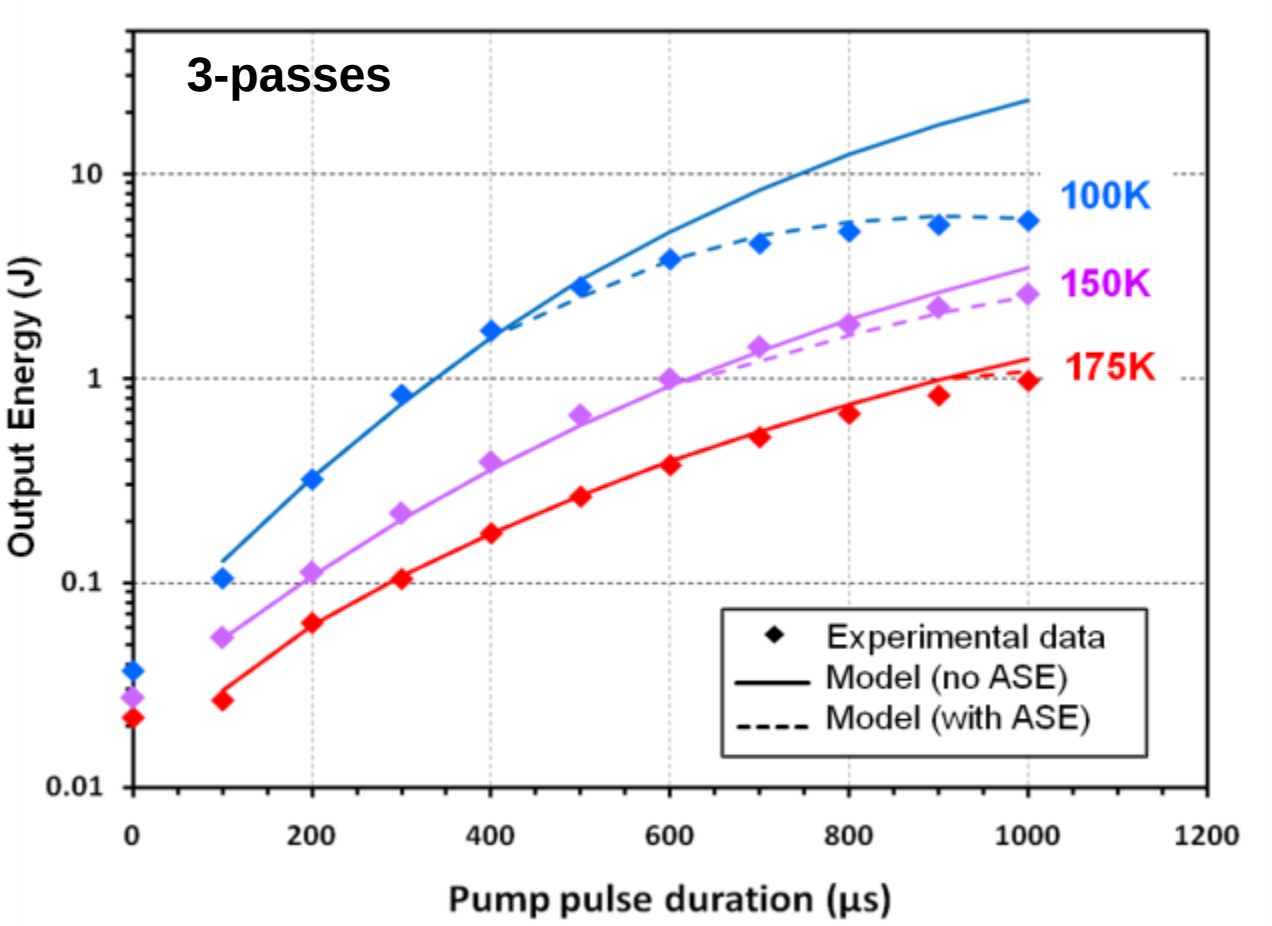


First Pulse Amplification Results

- 3 & 4-pass bow-tie extraction architecture

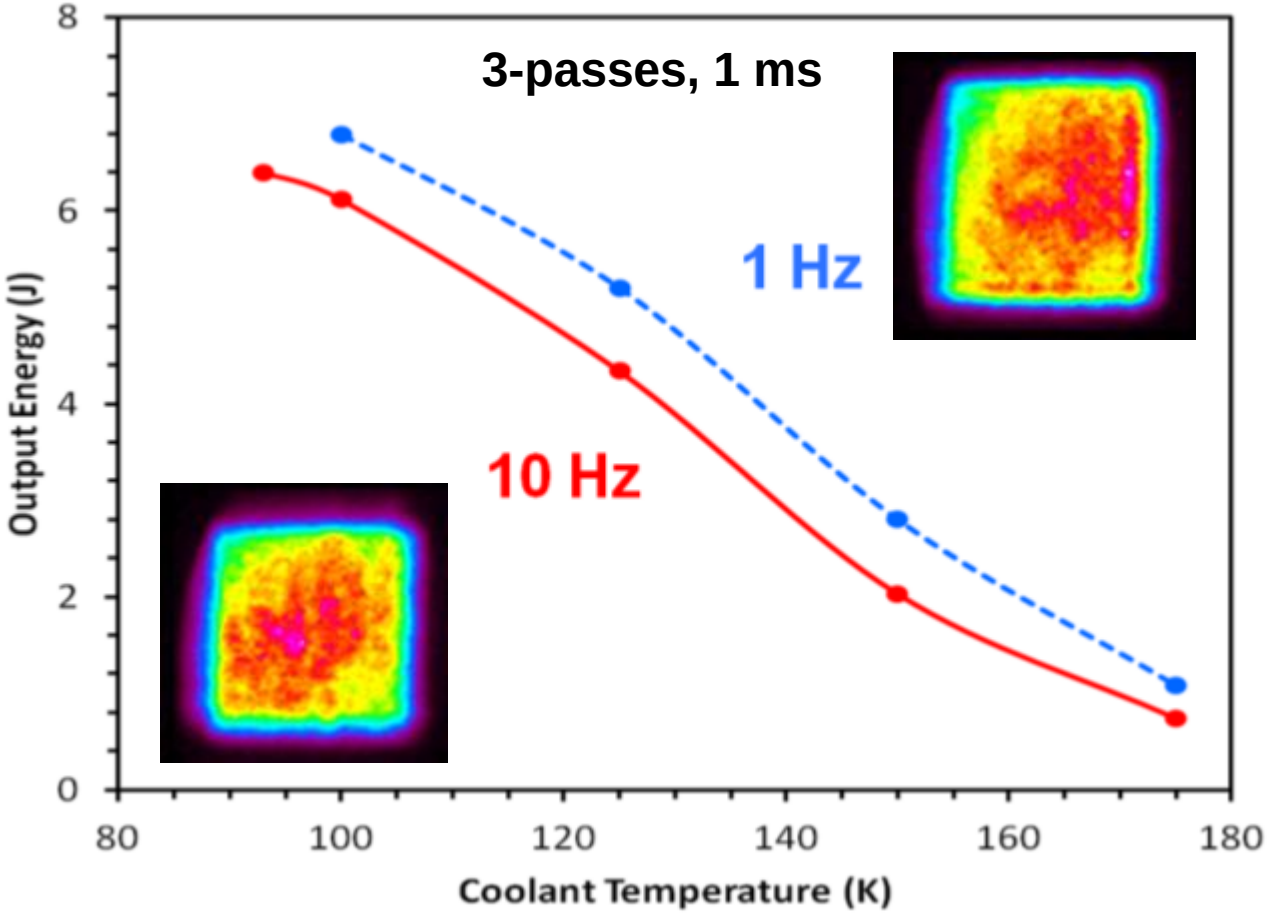


Pump Pulse Duration



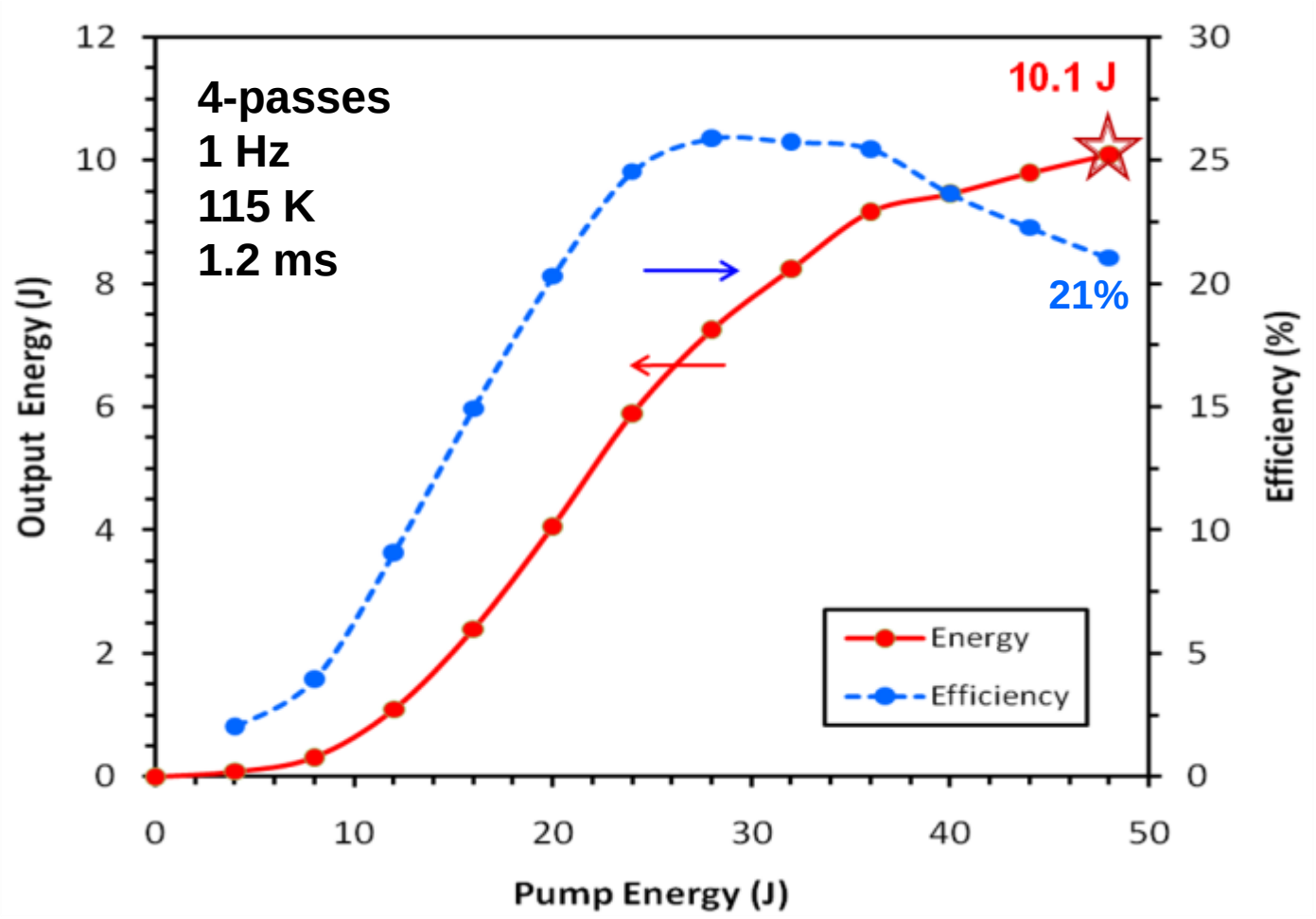
- ASE limiting performance at low temperature

Temperature Dependence & Beam Quality



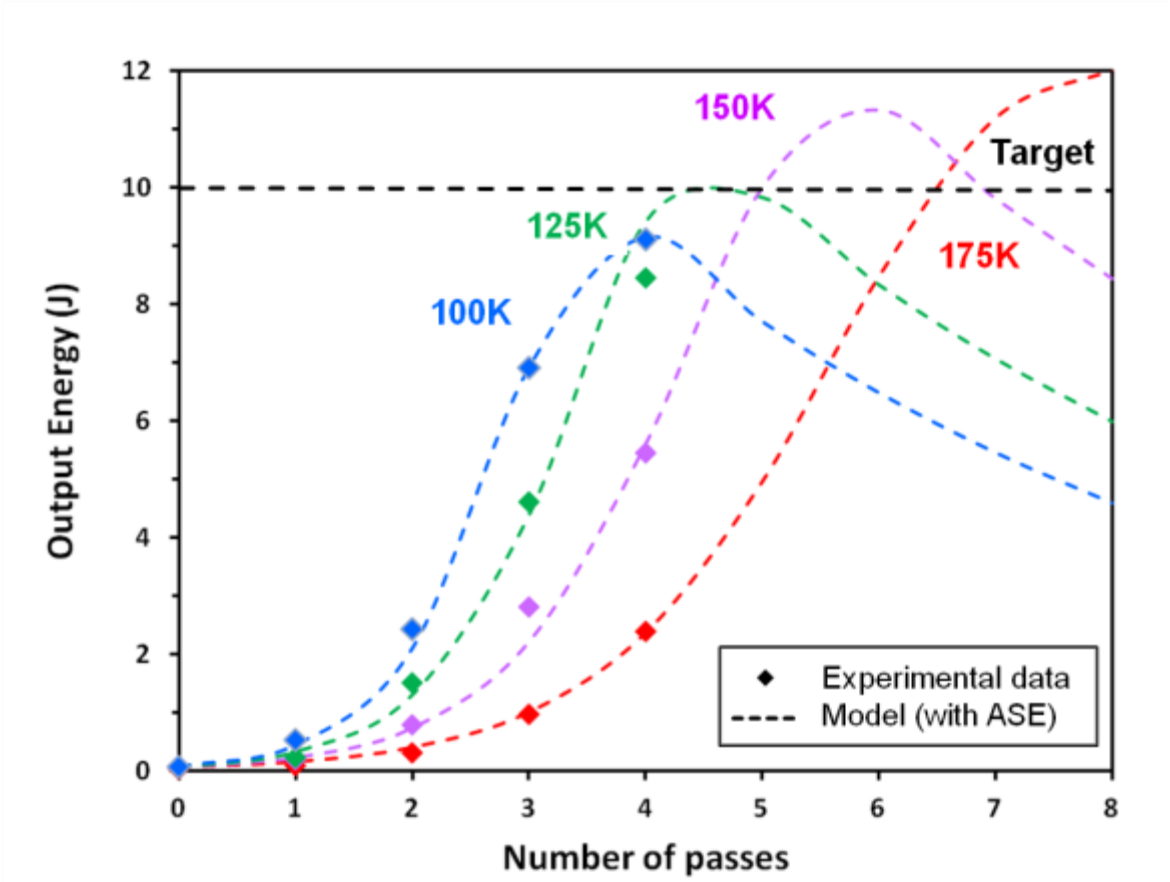
- Little difference between 1 Hz & 10 Hz profiles
  - Weak thermal aberrations

Conversion Efficiency



- More details in Optics Letters, 2175, 37, No.12 (2012)

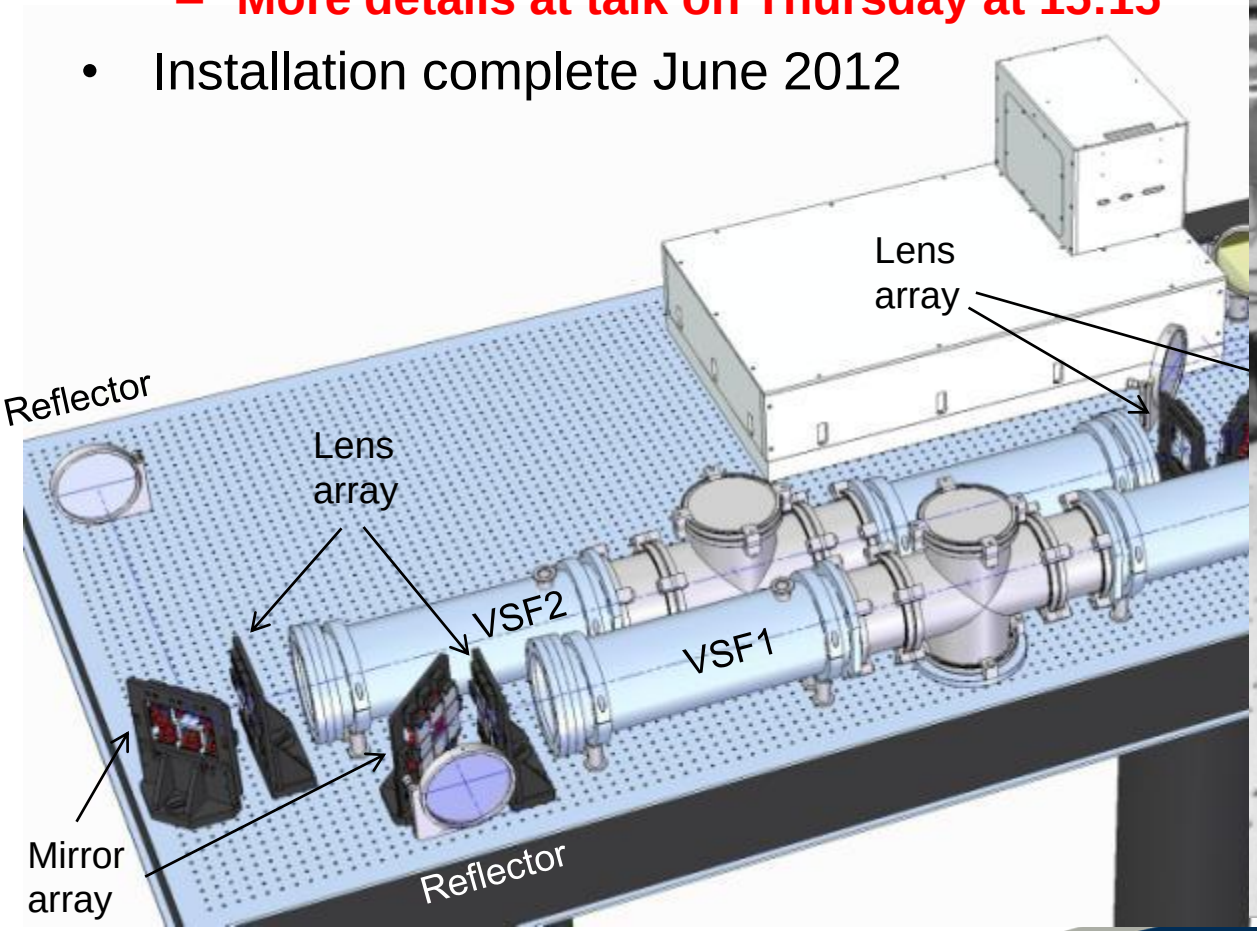
Experiment v. Modelling

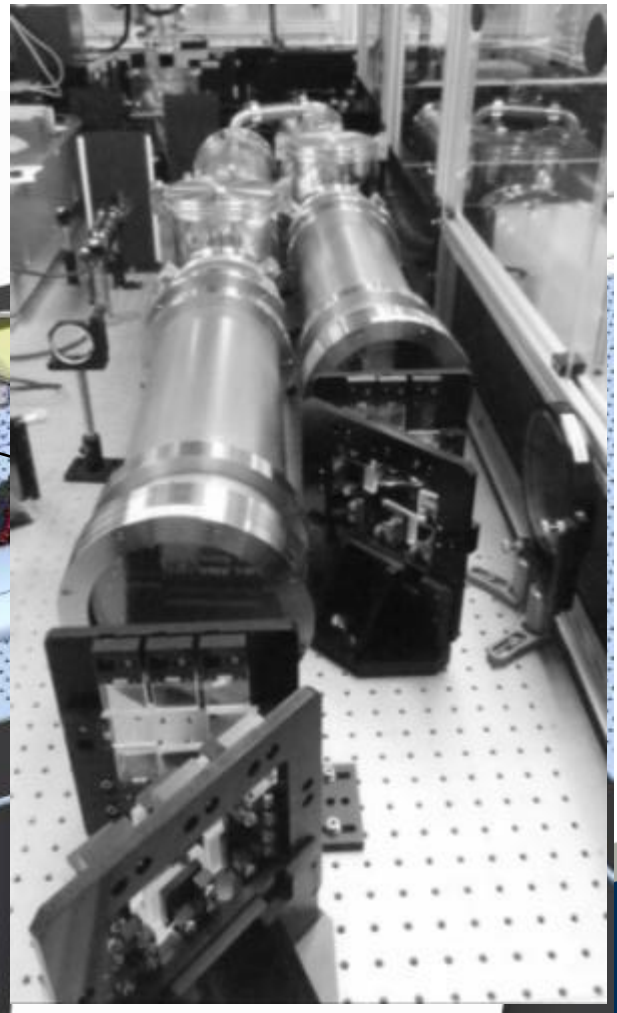


- Multi (6 to 8) pass architecture required to allow maximum energy extraction at > 150 K with minimal ASE loss

Advanced Image Relaying Multi-pass

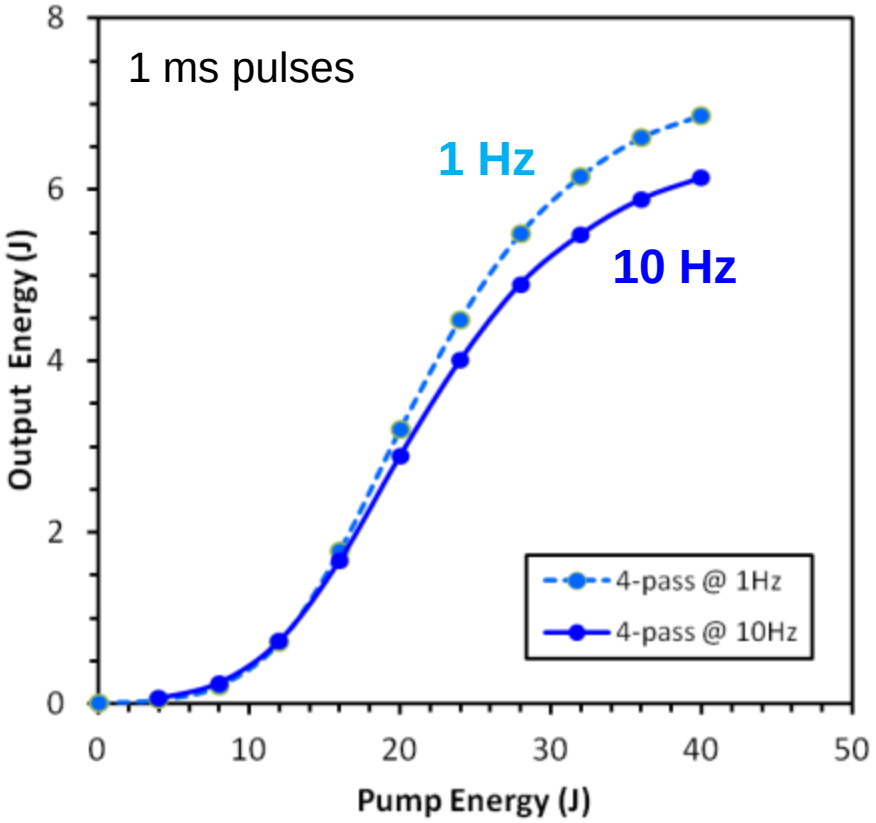
- Up to 8 passes, full relay imaging & spatial filtering
  - Allow efficient extraction at ≥ 150 K
  - **More details at talk on Thursday at 15:15**
- Installation complete June 2012



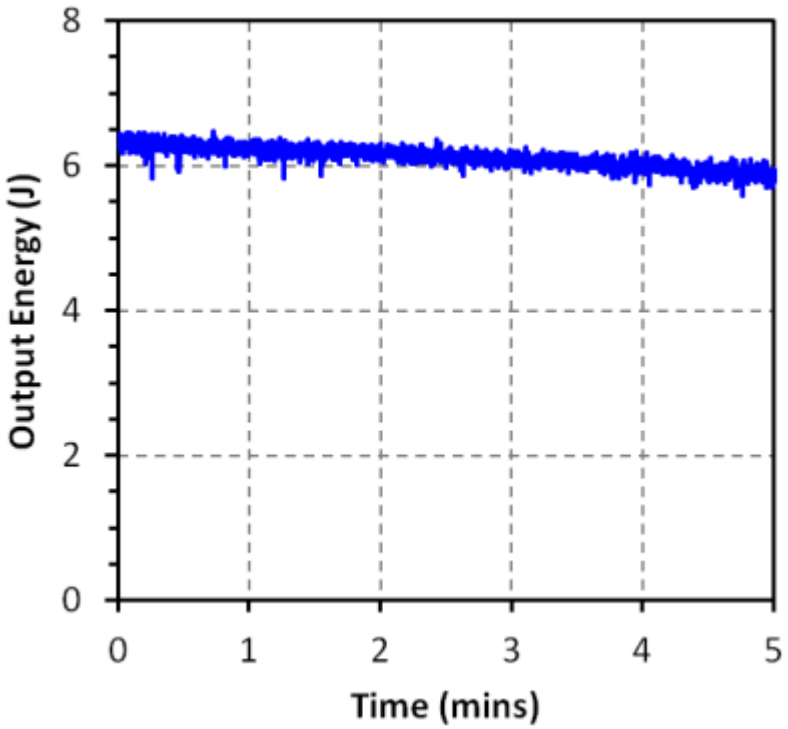


Recent Amplification Results – Summer 2012

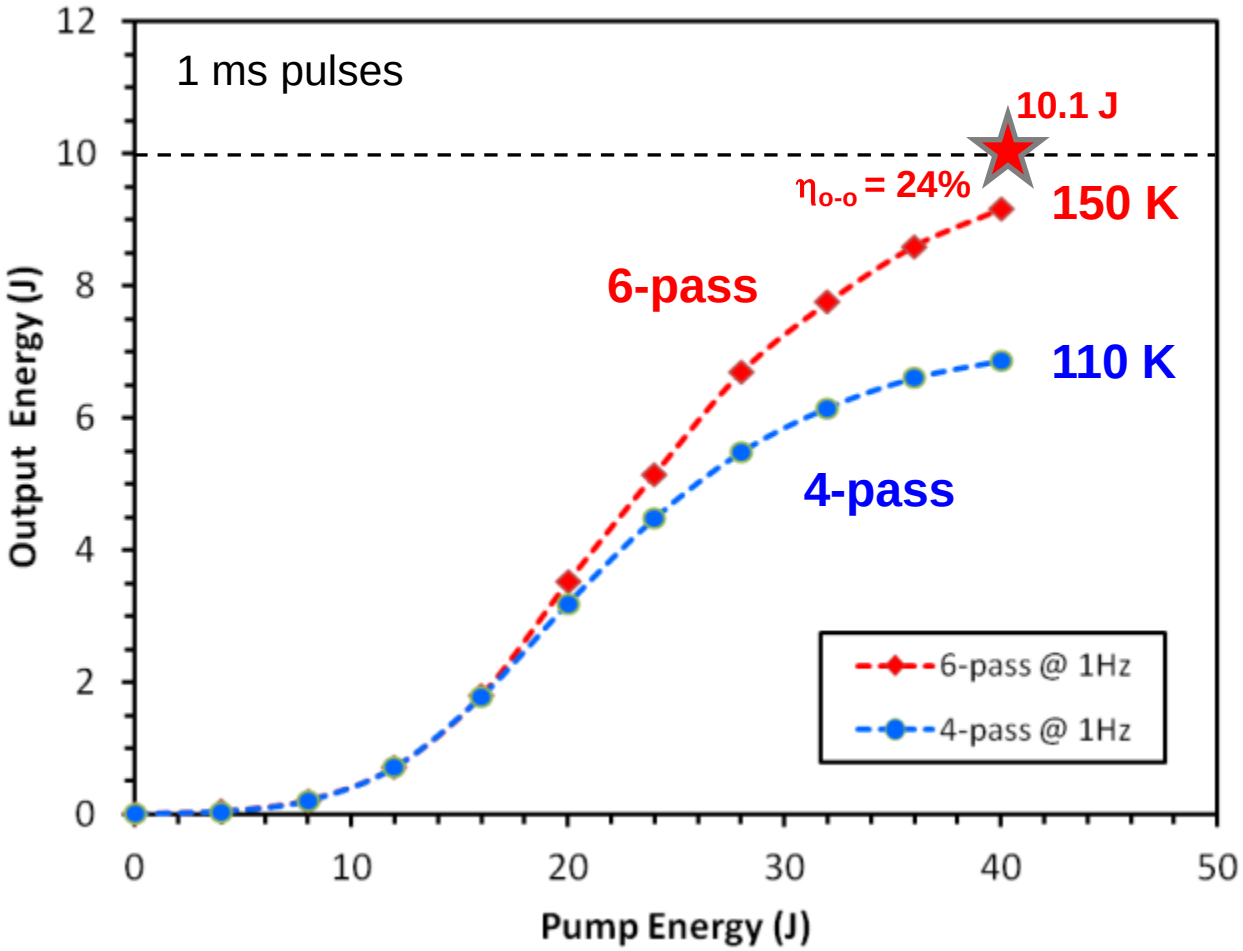
- 4-pass conversion at 110 K



- Energy stability at 10 Hz

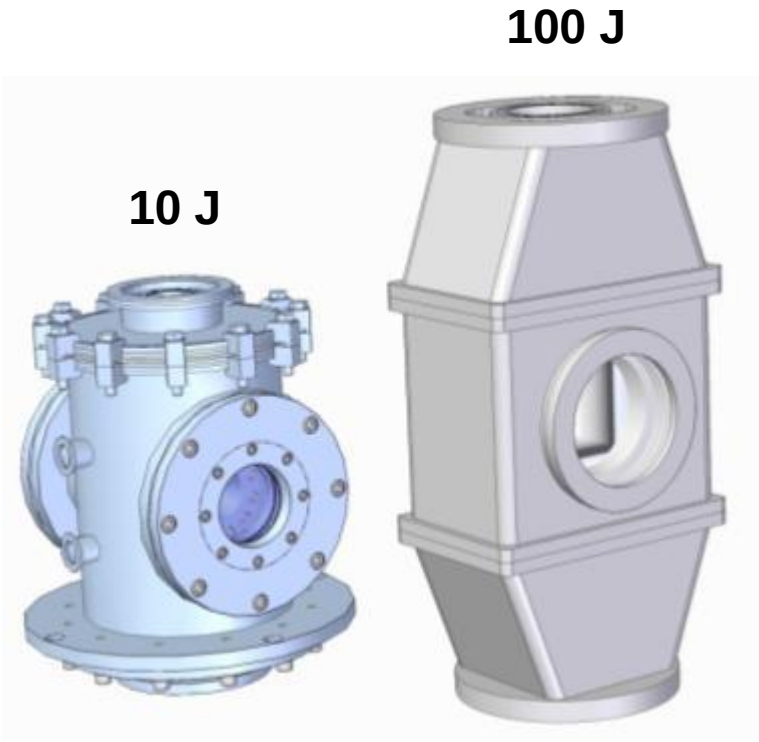


6-pass Performance at 1 Hz



Next Generation 100 J Amplifier

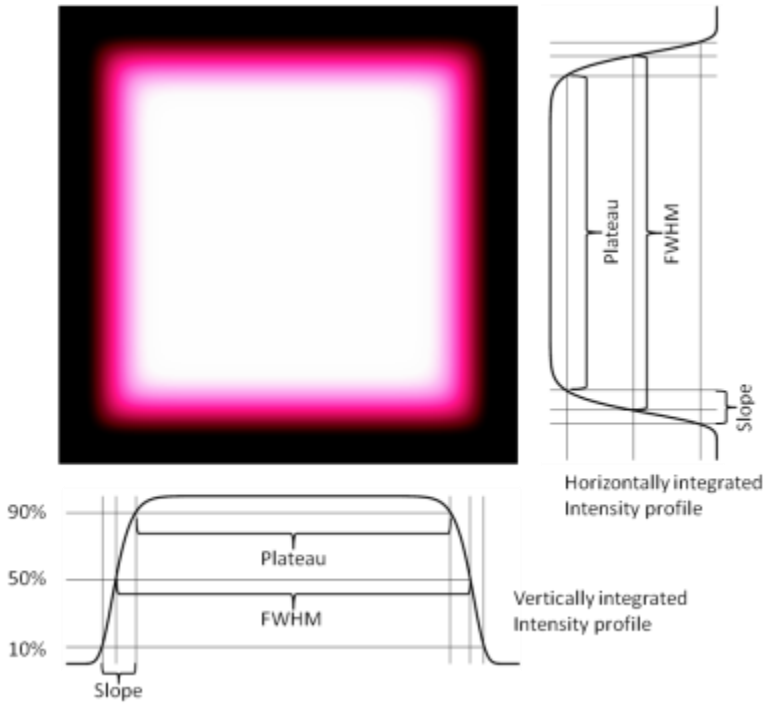
- Detailed design near completion
  - Single head seeded by DiPOLE 10J
  - 4-pass extraction architecture
- Tenders for key components issued
  - Gain media
  - Pump diodes
  - Cryo-system (to be issued shortly)
- New 100 J laboratory refurbished
- Component delivery/installation
  - Commence in 2013



Comparison of amplifier head sizes

Pump Diode Sources

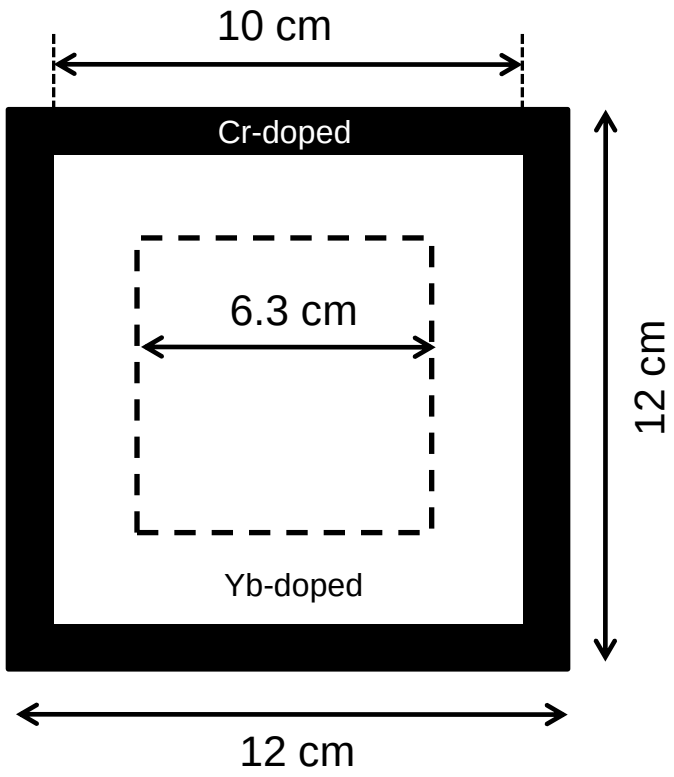
- Specification
  - 2 x 200 kW peak power
  - Pulse duration 1 ms
    - Tuneable 0.5 to 1.2 ms
    - Single-shot to 10 Hz
  - Target brightness ≥ 1.3 MW/cm²/sr
  - Divergence ratio 2.5° : 5.0° (H : V)
  - Square 63 mm x 63 mm beam
  - Centre wavelength 939.5 nm
    - >76% energy within ± 3 nm



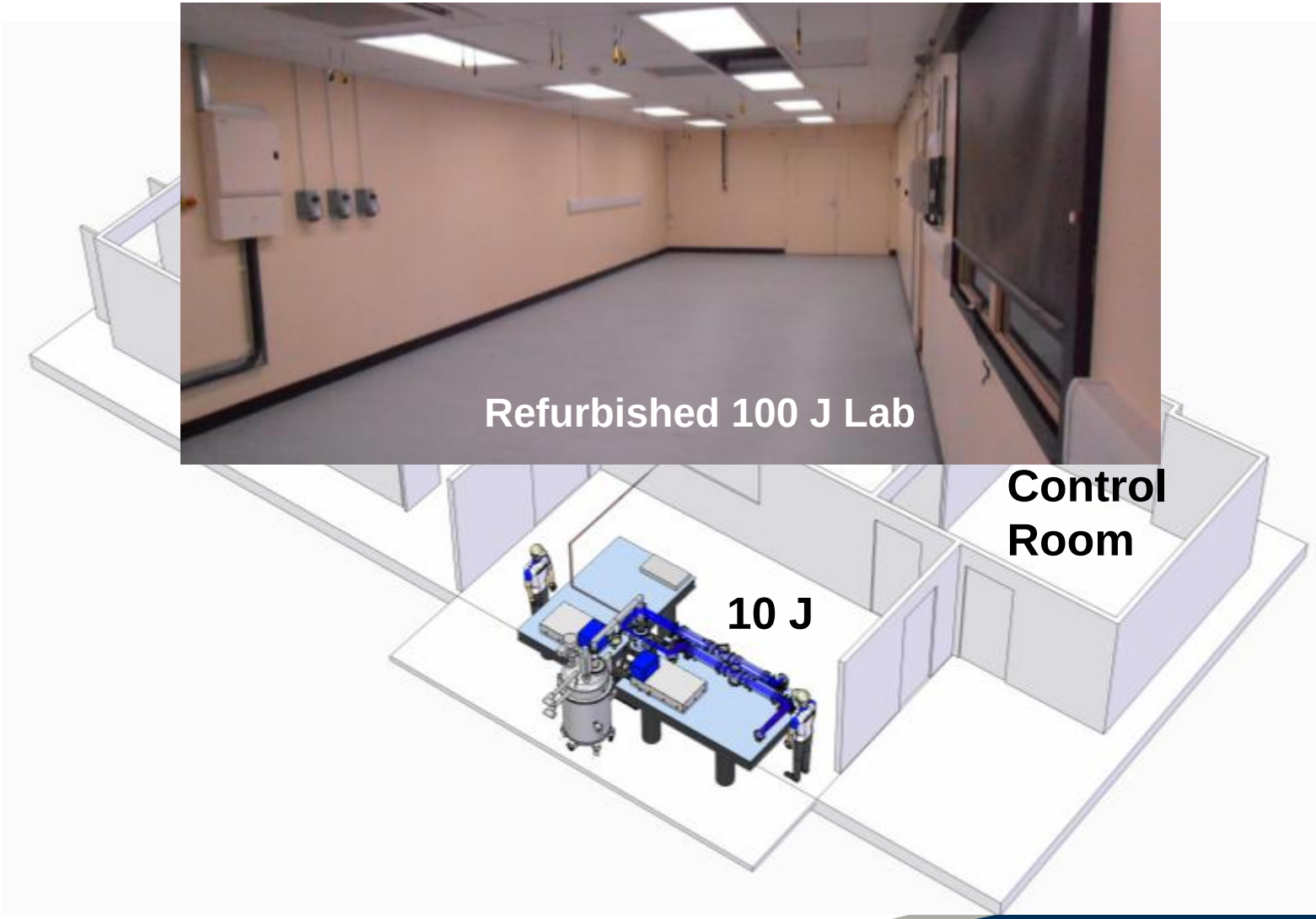
- Tender responses under review
  - 5 bidders

Gain Media

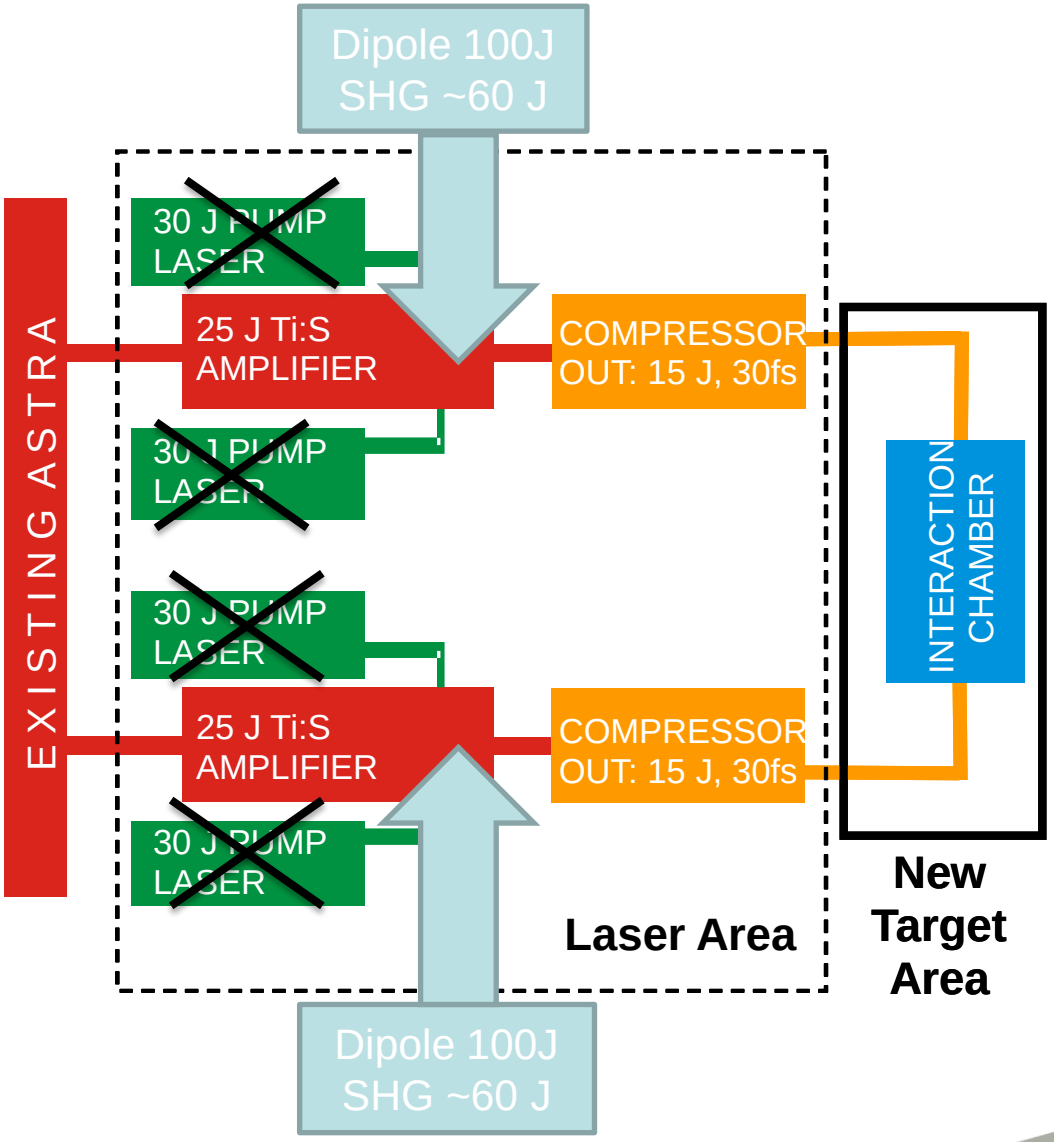
- Specification
  - 6 x Yb:YAG ceramic slabs
  - 120 mm x 120 mm square
  - Yb-doped region 100 mm x 100 mm
    - Doping 0.4, 0.6 & 1.0 at.%
  - Cr^{4+} cladding 10 mm wide
    - Attenuation @ 1030 nm = 3 ± 1 cm^{-1}
- Tenders responses under review
  - 4 bidders



Schematic of New DiPOLE Labs



Future Upgrade to Astra-Gemini



- Replace flashlamp based pump lasers with frequency-doubled DiPOLE 100 J
- New Ti:sapphire amplifier head design
- Two synchronised beams, independently configurable
  - Multi-Hz PRF
  - Contrast > 10^{10}
  - Intensity ~ 10^{22} W/cm^2

Conclusions & Plans

- Cryogenic gas cooled Yb:YAG amplifier offers potential for efficient, high energy, high repetition rate operation
  - 24% optical-to-optical efficiency demonstrated
  - Multi-slab architecture scalable to at least 1 kJ
- DiPOLE prototype amplifier shows promising results
  - Expect to demonstrate 10 J @ 10 Hz shortly
  - Development of temporally-shaped fibre front end
- Development of next-generation 100 J amplifier begun
- Plan to use this as a pump for new Ti:sapphire head to develop multi-Hz PW capability at CLF

Thank you for your attention!

Any Questions?

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